Base Shake Vibration Test Facility Verification Test Article Design Considerations

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Agenda

What is the Mechanical Vibration Facility?

What was the goal of the test effort?

What did we learn?

What is the Mechanical Vibration Facility?

One of several environmental test facilities housed at the Space Environments Complex (SEC) at NASA Glenn Research Center – Armstrong Test Facility in Sandusky, Ohio.

Designed to perform single axis sine vibration testing for MPCV Orion class payloads with a test article of 75,000 pounds and a center of gravity elevation of 23.6 feet above the top surface of the MVF table.

- 18 ft diameter table
- 16 vertical actuator assemblies (VAA)
- 4 horizontal actuator assemblies (HAA)
- Vertical sine sweeps of up to 1.25 g peak from 5 to 150 Hz and horizontal sine sweeps of up to 1.0 g peak from 5 to 150 Hz

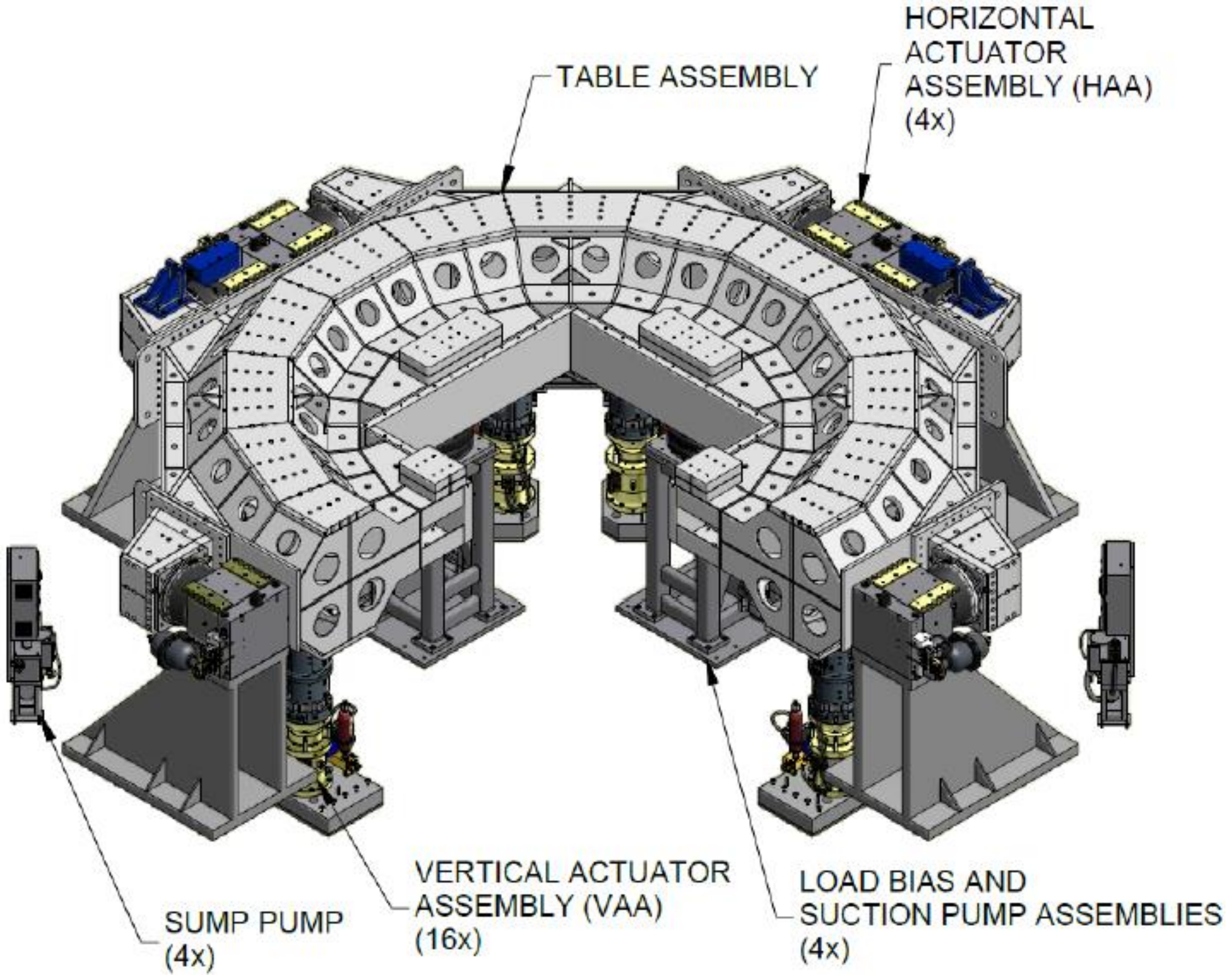

Figure 1: Mechanical Vibration Facility [1]

What is the Mechanical Vibration Facility?

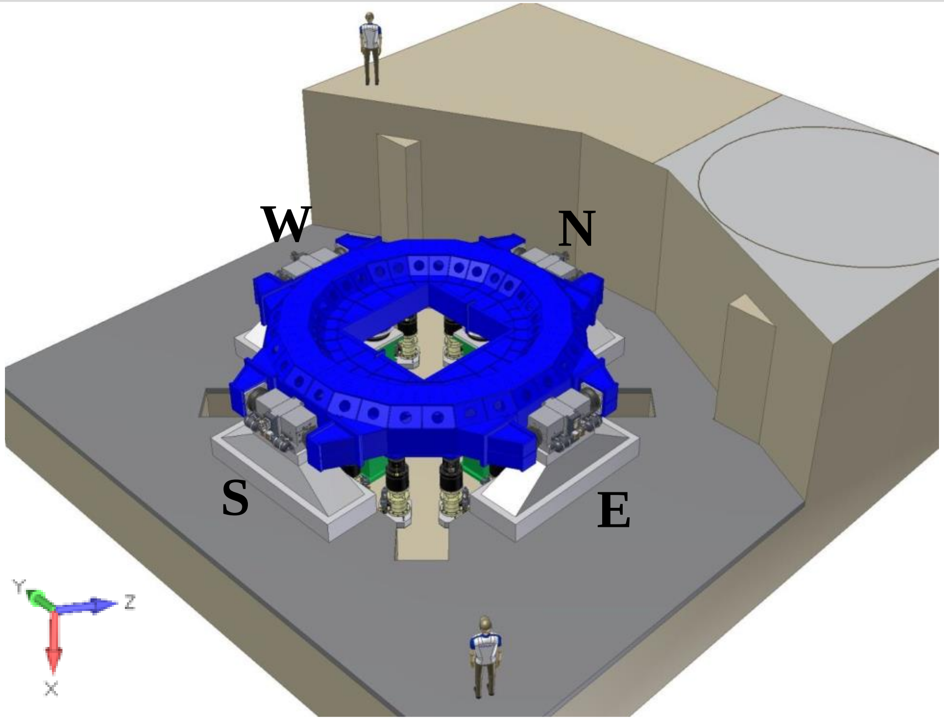

Figure 2: Mechanical Vibration Facility [2]

Specifications	
Total Vertical Dynamic Force	480,000 lbf
Total Horizontal Dynamic Force	170,800 lbf
Vertical Acceleration Level	1.25 G-pk
Horizontal Acceleration Level	1.00 G-pk

X-Axis Sine Vibration

4 drive signals → 16 VAA (groups of 4) → 4 control accelerometers

Y-Axis Sine Vibration

2 drive signals → 2 HAA → 4 control accelerometers
- North, South quadrant drives and HAA active

Z-Axis Sine Vibration

2 drive signals → 2 HAA → 4 control accelerometers
- East, West quadrant drives and HAA active

Drive signal, Control accelerometer feedback loop minimizes the overall error (RSS) of the 4 independent control accelerometers with respect to the defined input spectrum.

What was the goal of the test effort?

Commissioning a new or upgraded facility is needed to verify the vibration test facility, including its test personnel and test procedures, meet requirements and can perform testing in a safe and efficient manner. Commissioning activities are even more important for complex facilities such as the Mechanical Vibration Facility.

MVF Commissioning – 2021

- Facility commissioning needed to prepare for the Dream Chaser spaceplane sine vibration test campaign scheduled to begin August 2023. The Dream Chaser spaceplane is a product of Sierra Space and is the first-ever winged commercial spaceplane. Dream Chaser will support NASA resupply missions for the International Space Station.

- The Dream Chaser spaceplane will be the first ever flight hardware tested at the facility.

- A head expander (HE) for the MVF table that provides a continuous flat mounting surface with a maximum diameter of 16.25-ft was installed on the MVF table for the first time April 2021. The HE will be used for the Dream Chaser sine vibration test campaign.

- The Dream Chaser lateral axis test specification starts at 2 Hz and response limiting will be needed below 5 Hz.

- Due to lack of resources, need, and personnel availability, MVF largely remained idle from 2016 to 2021. Therefore, commissioning activities began early 2021 with the simplest test configuration possible – a bare vibration table.

What was the goal of the test effort?

2021 MVF Commissioning Verification Test Article – MPCV Orion Crew Module Launch Abort System (CM-LAS) Mass Simulator

- Originally, the CM-LAS mass simulator consisted of a blue painted tubular steel structure and a white painted wood constructed heat shield simulator. The mass simulator interfaced with the primary E-STA structure with 4 base attachment points.

- The CM-LAS was fixed-base modal tested and its FEM was correlated to test results up to 60 Hz.

- Following the completion of the E-STA sine vibration test campaign, CM-LAS remained in storage at SEC.

- The CM-LAS was chosen as the 2021-2022 VTA for multiple purposes: (1) Commission the MVF head expander with a test article (2) Demonstrate MVF sine vibration response limiting capabilities (3) Demonstrate MVF sine vibration response limiting capabilities below 5 Hz.

- For 2021-2022 facility commissioning and customer demonstration, the CM-LAS was modified by removing its wood constructed heat shield simulator component and increasing the base attachment points from 4 to 6. The yellow pedestals used for the 6 attachment points were also new.

- Prior to commissioning and demonstration activities, the new CM-LAS configuration was not modal tested so model correlation activities were not possible. This meant that response limits for the test article were defined using an uncorrelated model.

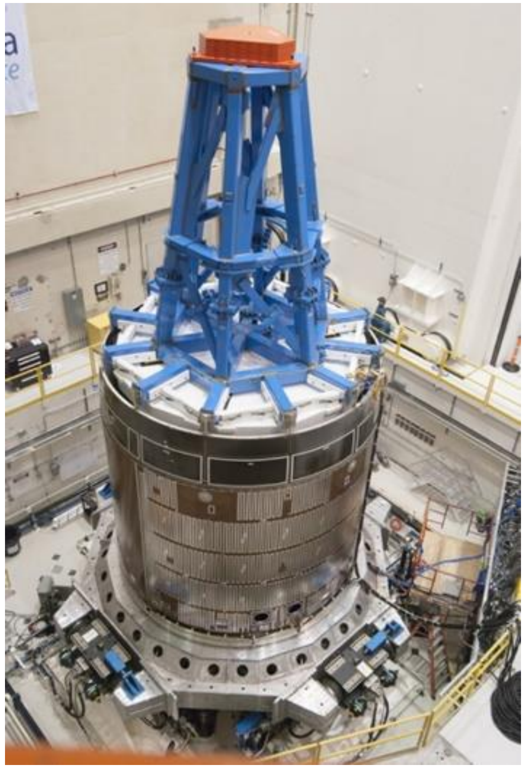

Figure 3: European Structural Test Article

Figure 4: CM-LAS Hard Mount

What was the goal of the test effort?

Test Configuration	Purpose
MVF Bare Table	Commission system to maximum acceleration levels achievable for the test configuration in all 3 test axes.
MVF Table + Head Expander	Commission system to maximum acceleration levels achievable for the test configuration in all 3 test axes.
CM-LAS Hard Mount	Demonstrate sine vibration response limited test to Dream Chaser X-axis test levels.
CM-LAS Half Stack, Soft Mount	Demonstrate sine vibration response limited test to Dream Chaser Y-axis and Z-axis test levels. Simulate Dream Chaser low frequency mode.

Figure 6: MVF Table + Head Expander

Figure 8: CM-LAS Hard Mount

Figure 5: MVF Bare Table

Figure 7: CM-LAS Half Stack, Soft Mount

What did we learn?

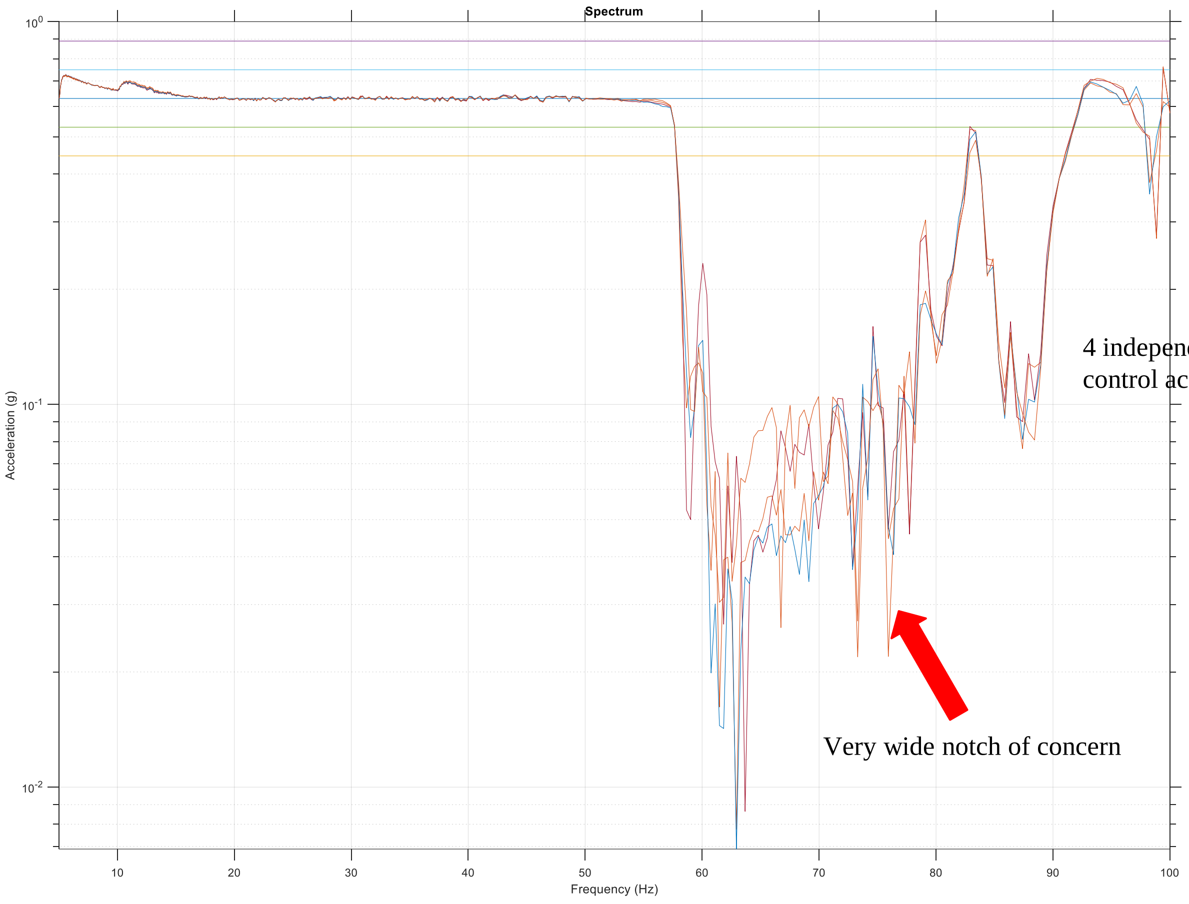

Figure 9: CM-LAS Hard Mount X-axis Control Plot

A notch in the test spectrum is expected during a vibration test with active response limiting, however during the 2021 test sequence there was question as to why the spectrum notch due to active response limiting was very wide and very deep.

- Was the control system unable to handle a deep notch such as the one shown?
- Was response limiting ineffective due to excessive ringing of the tubular steel structure?
- Was there a region of closely spaced modes?

What did we learn?

The Structural Analyst on this project defined acceleration response limits to eliminate the risk of damage to the test article incurred by resonance.

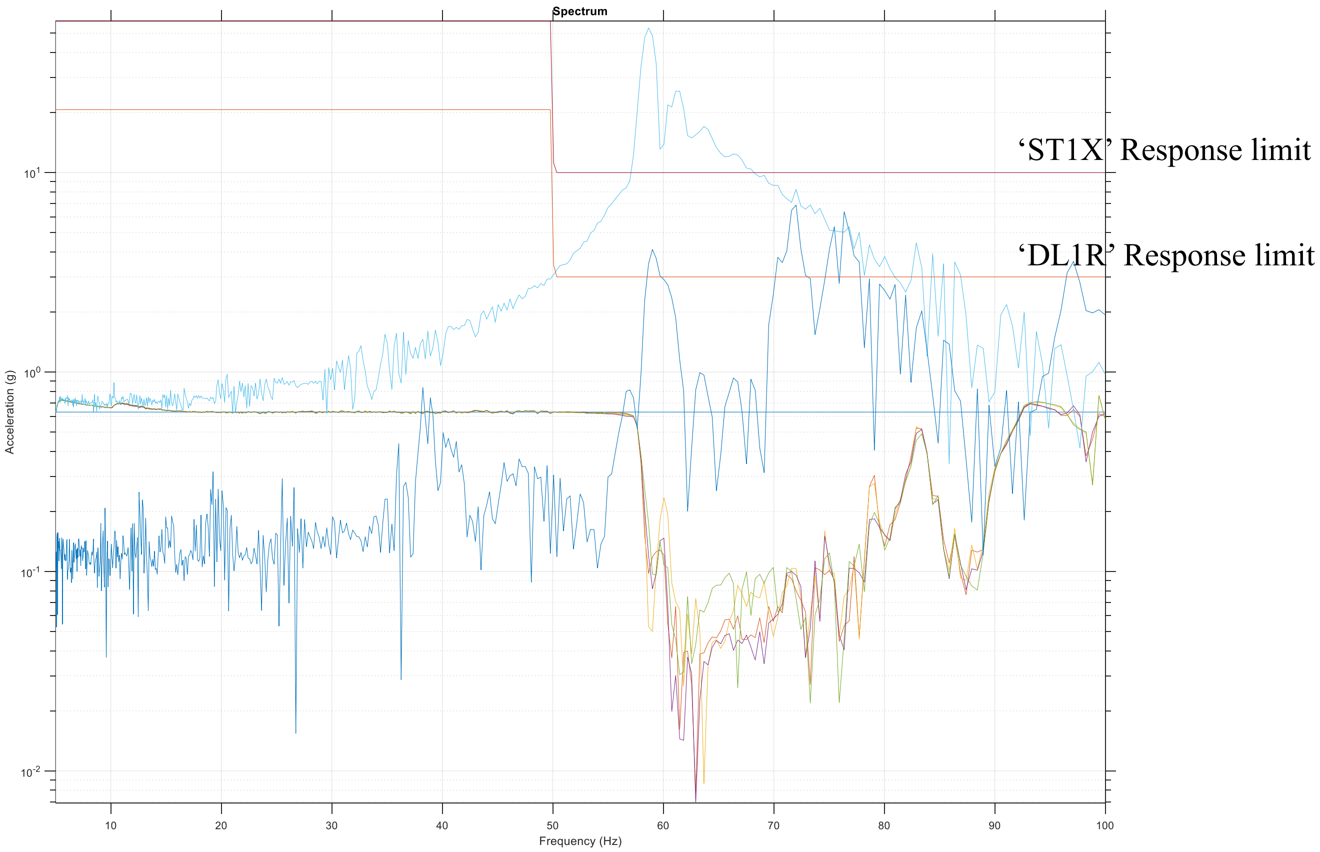

Figure 10: CM-LAS Hard Mount X-axis Control & Response Plot

All instrumentation is given a code (up to 5 digits) for the facility data acquisition system. This code is generally shorthand that indicates where the instrumentation is located on the test article.

'ST1X' – Vertical accelerometer on the stub of the CM-LAS, East quadrant

'DL1R' – Radial accelerometer on the lower diagonal of the CM-LAS, East quadrant

The plot shows that the wide notch of concern is due to engagement of the 'ST1X' and 'DL1R' response limits. The response limits engage when an accelerometer designated in the control software as a response limit crosses the set acceleration threshold and disengages when the response is below that set threshold.

The modal test results helped further explain the vibration test results.

What did we learn?

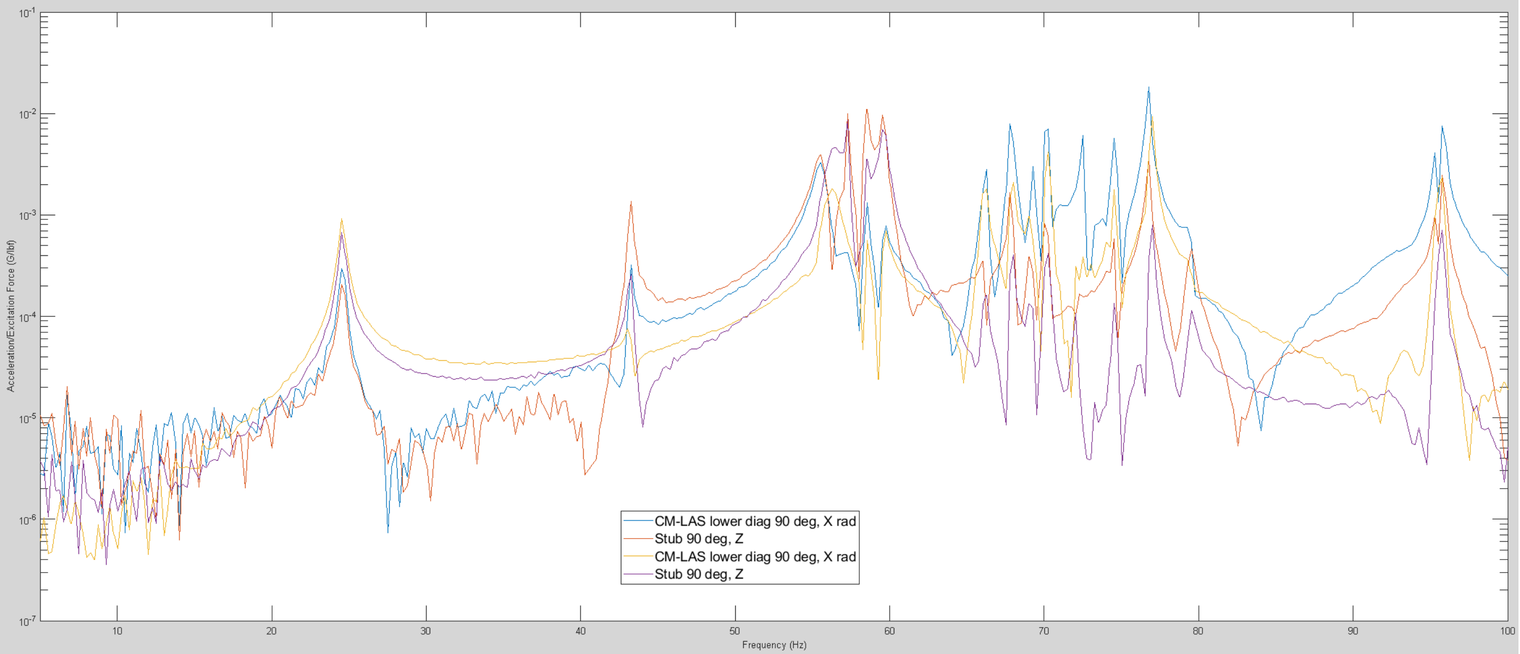

Figure 11: ‘DL1R’ and ‘ST1X’ Modal Test Results
Multiple Input Hammer Test – 2 reference channels per response channel

Modal test results indicated that the width of the response limited region from 56-80 Hz was due to closely spaced modes which all had similar levels of response.

- During commissioning, these closely spaced modes made it difficult to commission the vibration control software

The damping values of the CM-LAS modes were all well below the damping of a well-designed test article.

- Explains the need for deep notching to keep the response level of limit channels below the abort level set in the system

With better understanding of the CM-LAS response limits defined by the Structural Analyst and a better understanding of the CM-LAS dynamics, the test team was able to focus on commissioning the vibration control software.

What did we learn?

CM-LAS Fixed Base Modal Results			
Mode	Frequency (Hz)	Damping (%)	Description
1	24.29	0.321	CM-LAS 1st bending - 1
2	24.57	0.471	CM-LAS 1st bending - 2
3	43.20	0.150	CM-LAS 1st torsion
4	55.48	0.606	CM-LAS 2nd bending - 1
5	56.31	0.723	CM-LAS 2nd bending - 2
6	57.30	0.060	Diagonal/stub vertical mode - 1
7	58.43	0.099	Diagonal/stub vertical mode - 2
8	58.43	0.113	Diagonal/stub vertical mode - 3
9	58.54	0.110	Diagonal/stub vertical mode - 4
10	59.62	0.241	Diagonal/stub vertical mode - 5
11	66.09	0.098	CM-LAS 2nd torsion
12	67.80	0.060	Diagonal/stub vertical mode - 6
13	67.99	0.049	Diagonal/stub vertical mode - 7
14	69.15	0.048	Diagonal/stub vertical mode - 8
15	69.94	0.056	Diagonal/stub vertical & tangential mode - 1
16	70.28	0.059	Diagonal/stub vertical & tangential mode - 2
17	70.76	0.078	Diagonal/stub vertical & tangential mode - 3
18	71.98	0.072	Diagonal/stub tangential mode - 1
19	72.48	0.064	Diagonal/stub tangential mode - 2
20	73.19	0.052	Diagonal/stub tangential mode - 3
21	74.09	0.029	Diagonal/stub tangential mode - 4
22	74.62	0.029	Diagonal/stub tangential mode - 5
23	76.71	0.077	CM-LAS 3rd bending - 1
24	76.98	0.090	CM-LAS 3rd bending - 2
25	79.46	0.258	CM-LAS 1st axial/torsion
26	93.26	1.161	CM-LAS 2nd axial/torsion
27	95.38	0.047	CM-LAS lobe - 1
28	95.81	0.083	CM-LAS lobe - 2

CM-LAS low damping values increased the difficulty of the response limited sine vibration test.

What did we learn?

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Verification Test Article Design Considerations

- Mass and strength properties
  - Does the VTA have mass properties that encompass the heaviest/largest anticipated test article?
  - Does the VTA have sufficient strength to withstand the inertial loading produced by the anticipated highest level test spectra?

- Modal properties
  - Does the VTA have repeated or very closely spaced modes?
  - Should the VTA be relatively stiff driving its fundamental high effective mass modal frequencies up or should it be soft to lower them?
  - Is the VTA damping approximately the same as the anticipated test article?

- Response limits
  - If acceleration measurements are to be used for response limiting, was the VTA FEM used to define the response limits correlated to modal test data?

A well-designed verification test article is essential for facility commissioning success.

Questions?

References

[1] Team Corporation “Mechanical Vibration System: Operation and Maintenance Manual” September 2011

[2] Otten, Kim D., Suárez, Vicente J., Le, Dzu K., “Status and Design Features of the new NASA GRC Mechanical Vibration Facility (MVF)” IEST *ESTECH*, 2010